# Investigating Cryogenic Pump Lifetime and Exploring Alternative Designs

Katie Baakkonen, Harvey Mudd College

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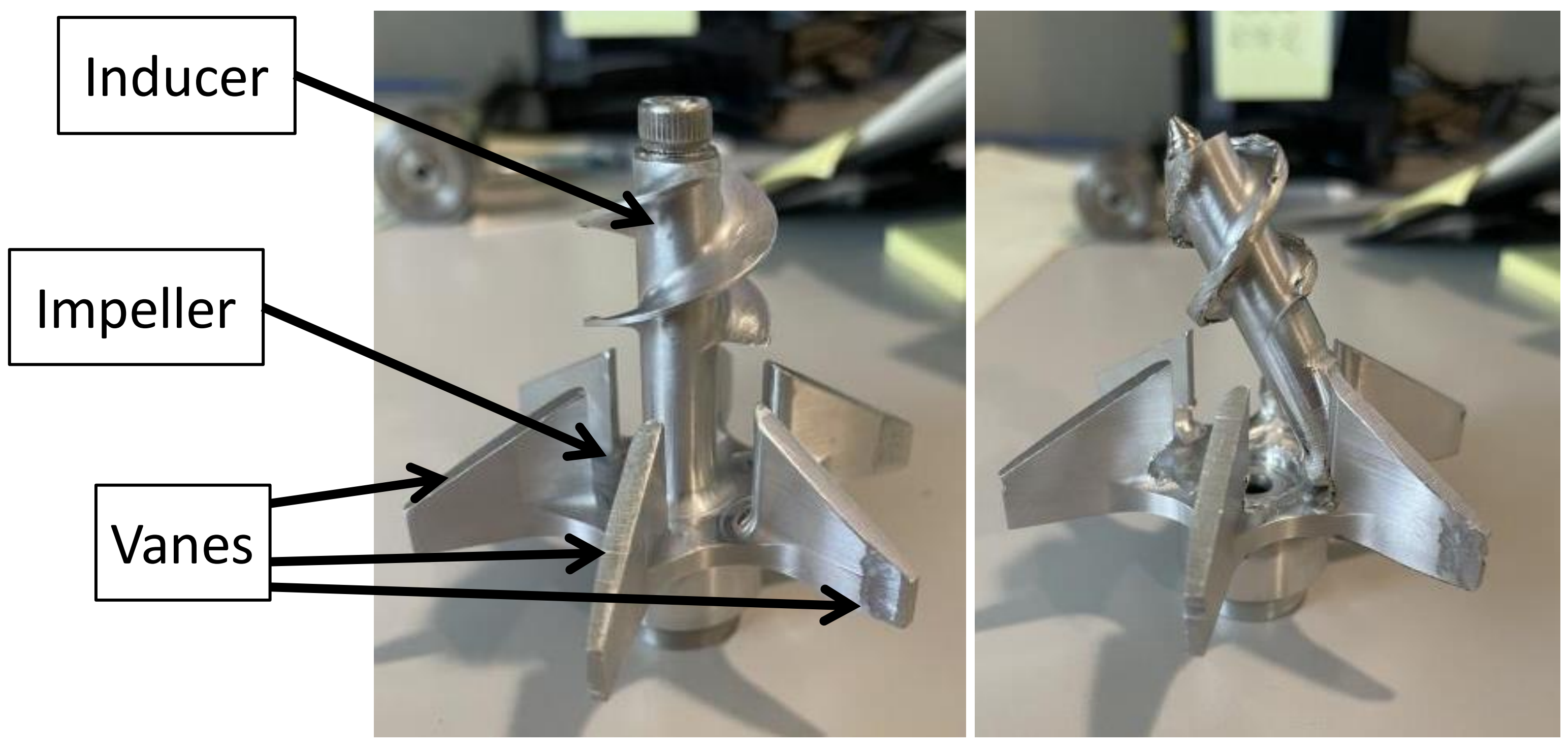
## Motivation

Cryogenic pumps are necessary for the operation of several neutrino experiments at Fermilab where some of the primary components of the detectors are liquid argon and liquid nitrogen. The pumps currently in use are centrifugal pumps with a small, vortex impeller, manufactured by Barber Nichols. This pump has an average lifetime of 8000 hours. Such a short lifetime means that each pump requires maintenance multiple times a year, which is not optimal. Over the last decade, engineers trying to improve the lifetime have tried using high-performance bearings inside of the pump but did not see a noticeable increase in lifetime. The goal of this project was to determine what aspects of the current pump design could be modified to improve the lifetime of the pump such that it would only require maintenance once a year.

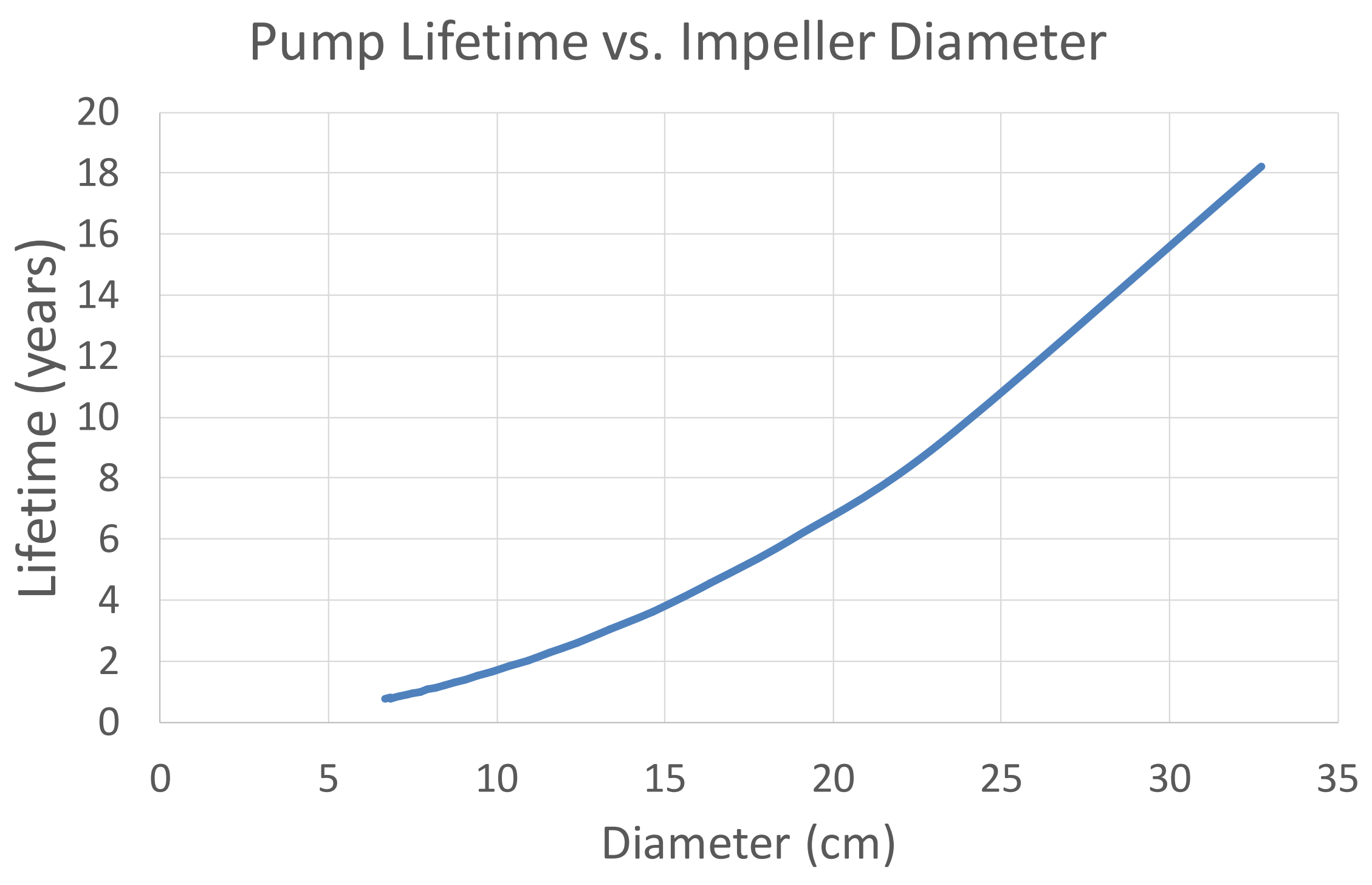


**Left – Intact impeller with inducer designed by Barber Nichols**

**Right – Failed impeller with inducer**

## Methods

Through researching centrifugal pumps and reverse engineering the pump currently in use, several areas were identified as potential causes of the short lifetime. These elements were then targeted in computational fluid dynamics simulations.



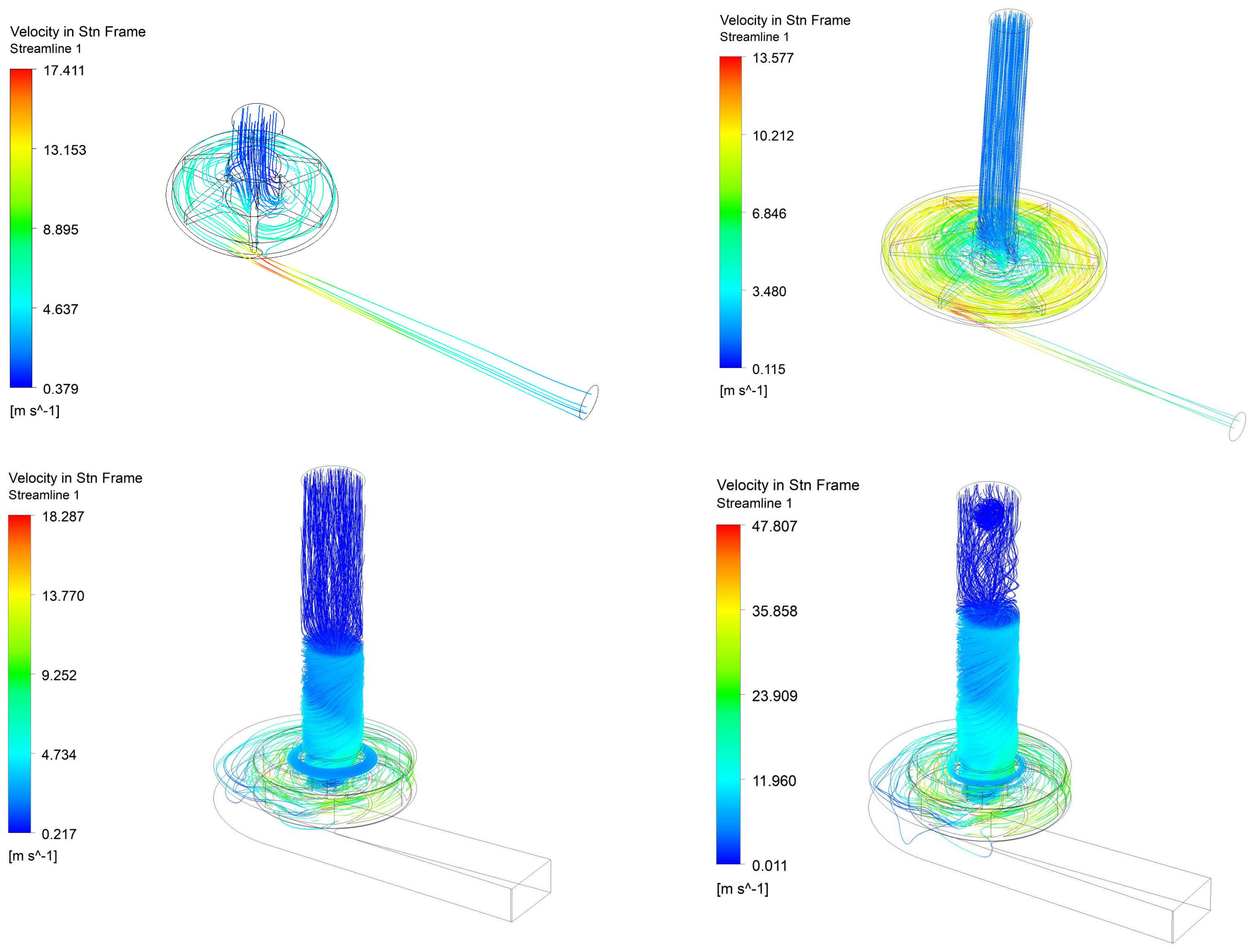
**Bearing lifetime as a function of impeller diameter. This relationship was determined by calculating the speed the pump would have to spin at to achieve a flow rate of 33.3 liters at each diameter. As the diameter of the impeller gets larger, the speed to achieve the same pressure and flow decreases. Thus, rotational speed is inversely related to bearing lifetime. Note that this lifetime calculation neglects to consider the changing radial forces caused by increasing the impeller size.**

$$\frac{Q_1}{Q_2} = \frac{n_1 D_1^2}{n_2 D_2^2}$$

**Equation 1 – One of the pump affinity laws used to calculate the flow rate of a pump in different conditions. $Q$ is flow rate, $n$ is rotational velocity, $D$ is impeller diameter.**

$$L_{10} = \frac{(C/P)^{e} \times 10^6}{60 \times N}$$

**Equation 2 – Used to calculate bearing lifetime with 90% reliability. $C$ is dynamic capacity, $P$ is equivalent bearing load, $N$ is rotational speed, $e$ is a constant specific to the bearing type. $(C/P)^{e}$ was extrapolated by using the known bearing lifetime at 5700 rpm. This equation was then used to find the bearing lifetime at different speeds.**



**CFD analysis of different pumps showing velocity and path of fluid, simulated using ANSYS CFX.**
**Top left – Barber Nichols impeller without inducer*, running at 5700 rpm**
**Top right – Barber Nichols-inspired design with twice the diameter, running at 2200 rpm**
**Bottom left – Curved impeller with radius twice the size of BN, running at 2200 rpm**
**Bottom right – Curved impeller with radius twice the size of BN, running at 5700 rpm**
***Prior use of the pump has shown that the inducer has an insignificant effect on performance.**

## Results and Conclusions

There were several aspects of the pump design that were thought to be able to influence the pump's performance:

- Impeller diameter
- Vane shape
- Volute shape

Changing each of these details would affect radial force on the bearings or the required rotational speed of the impeller to achieve a given flow rate. Bearing life is a function of rotational speed and radial force, so if the same flow rate could be achieved at a lower speed and radial force, the pump would likely last longer. Future work on this project will include further evaluation of these design parameters and searching for a combination that would be predicted to result in a longer lifetime.

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